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(54) **DIAGONAL OPENINGS IN PHOTODEFINABLE GLASS**

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B41J 2/16 (2006.01)
B41J 27/20 (2006.01)

(52) **U.S. Cl.**

CPC ***B41J 2/1433*** (2013.01); ***B41J 2/14145*** (2013.01); ***B41J 2/1603*** (2013.01); ***B41J 2/1623*** (2013.01); ***B41J 2/1629*** (2013.01); ***B41J 2/1634*** (2013.01); ***B41J 27/20*** (2013.01); *B41J 2002/14419* (2013.01); *Y10T 428/24314* (2015.01)

(58) **Field of Classification Search**

CPC B41J 2/1433; B41J 27/20; B41J 2002/14419; B41J 2/1631; B41J 2/1623; B41J 2/162; B41J 2202/22; B41J 2/14201

See application file for complete search history.

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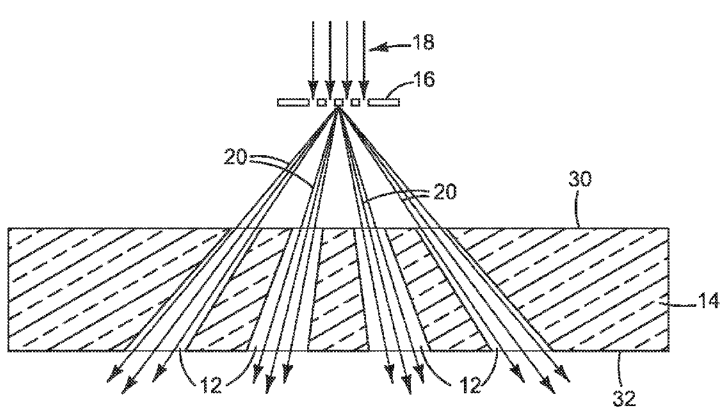
(57) **ABSTRACT**

In one example, a method for making diagonal openings in photodefinable glass includes exposing part of a body of photodefinable glass to a beam of light oriented diagonally to a surface of the body at an angle of 5° or greater measured with respect to a normal to the surface of the body and removing some or all of the part of the body exposed to the light beam to form a diagonal opening in the body.

10 Claims, 10 Drawing Sheets



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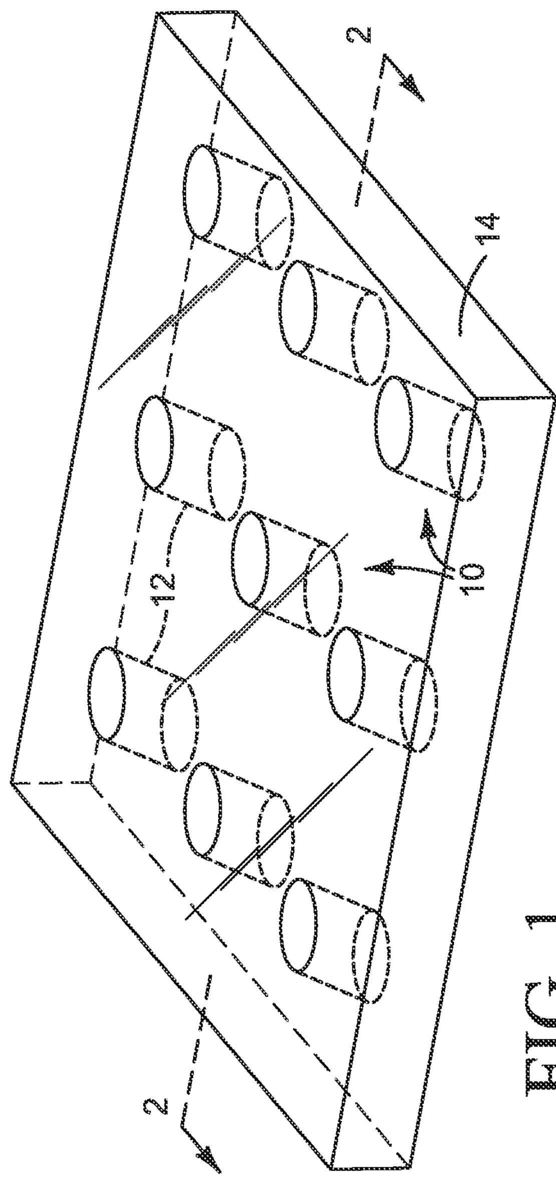

FIG. 1

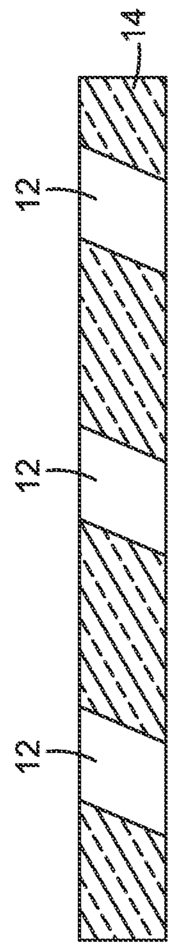

FIG. 2

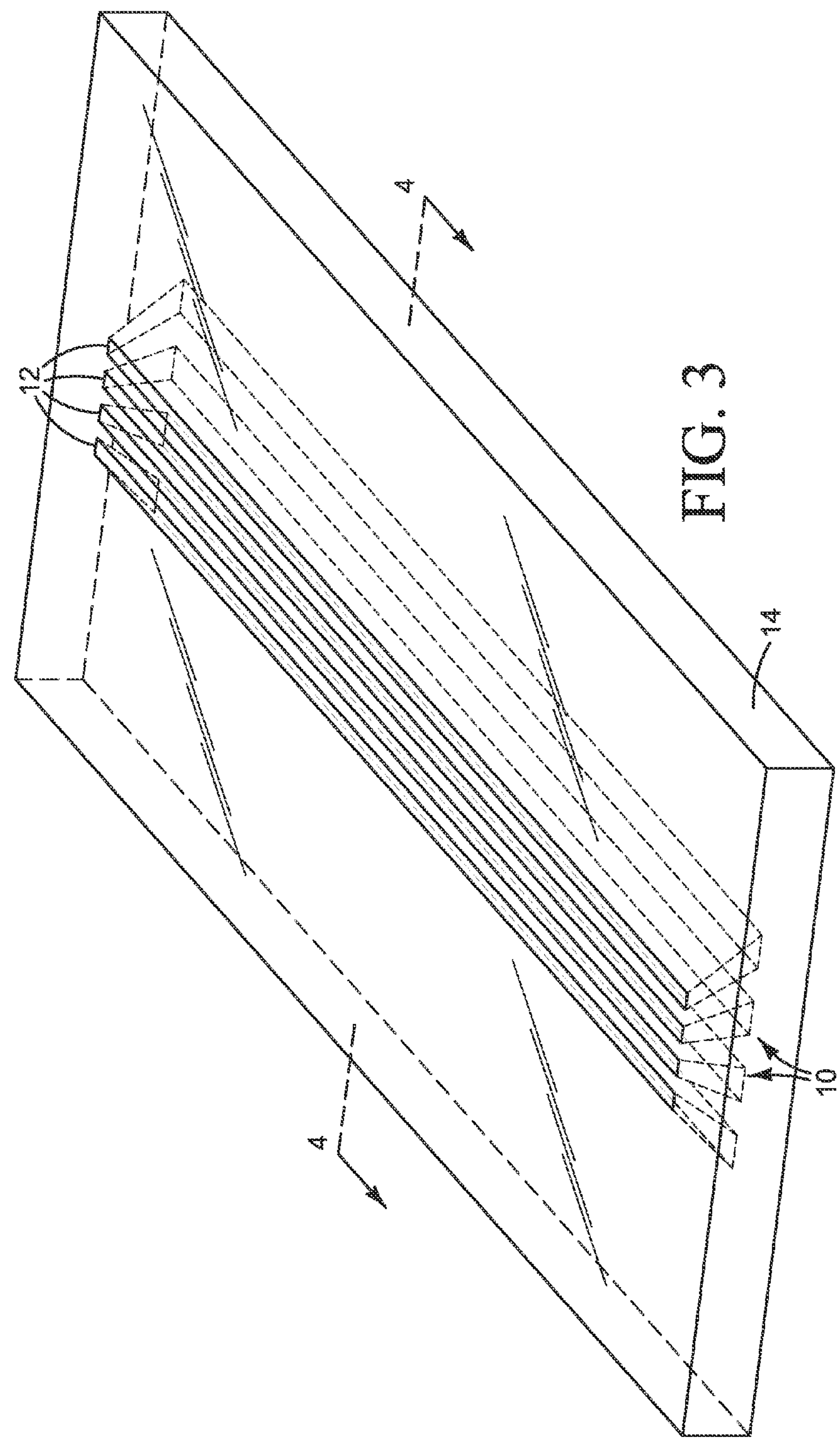

FIG. 3

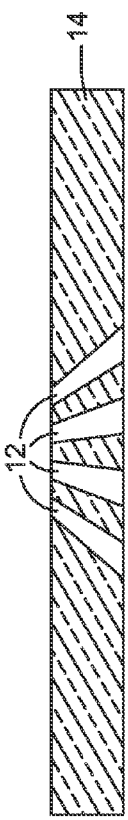

FIG. 4

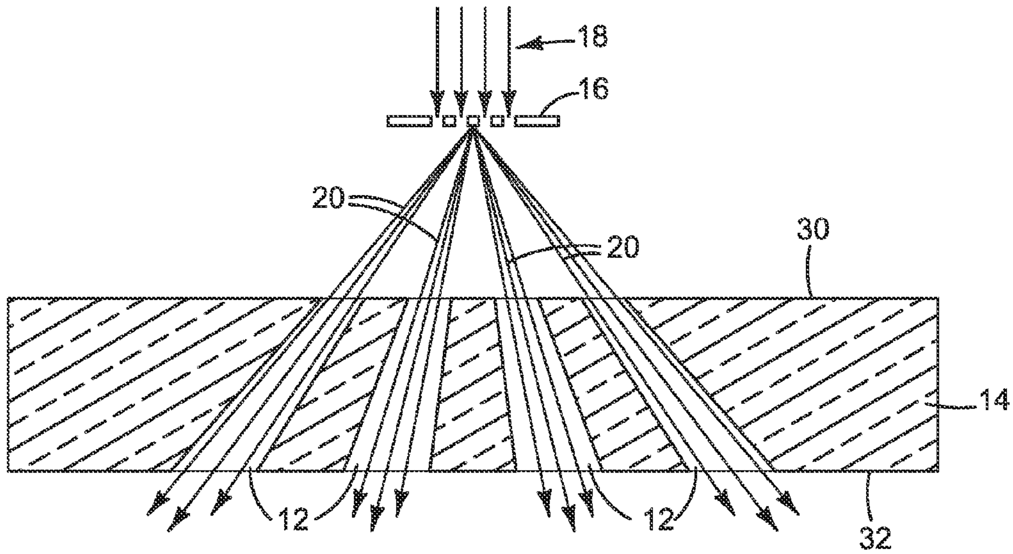

FIG. 5

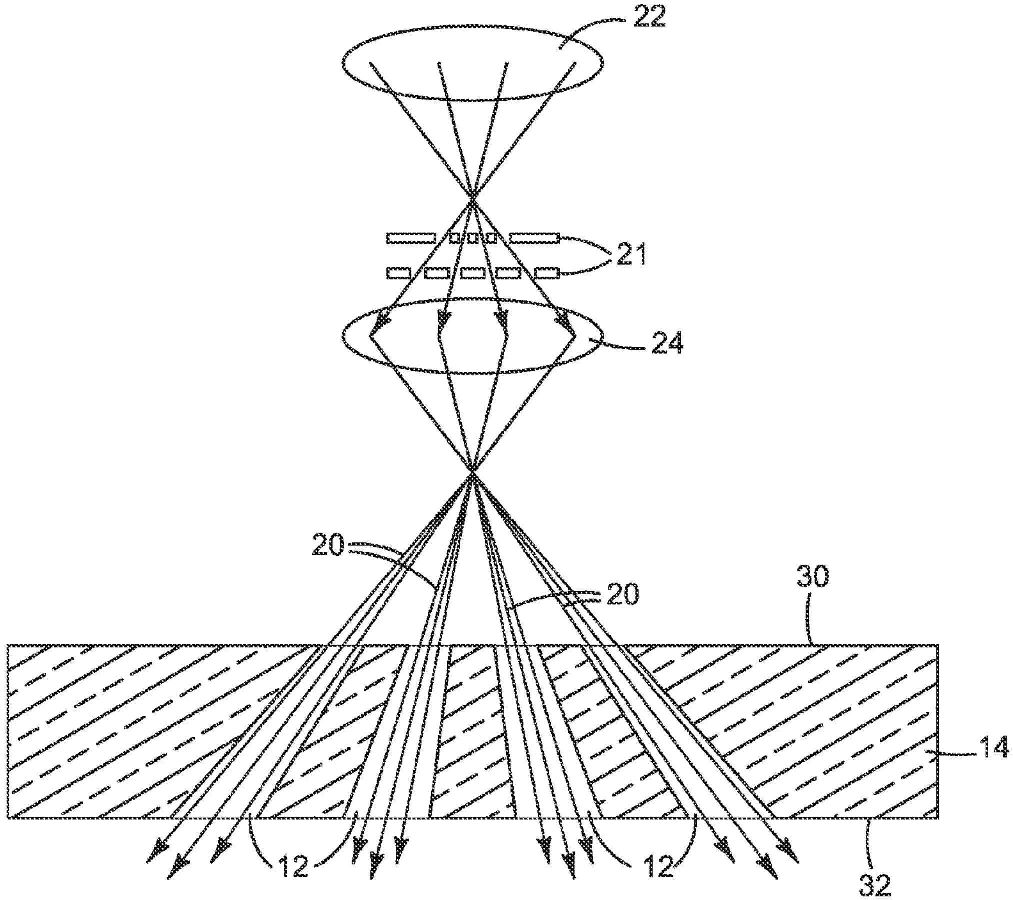

FIG. 6

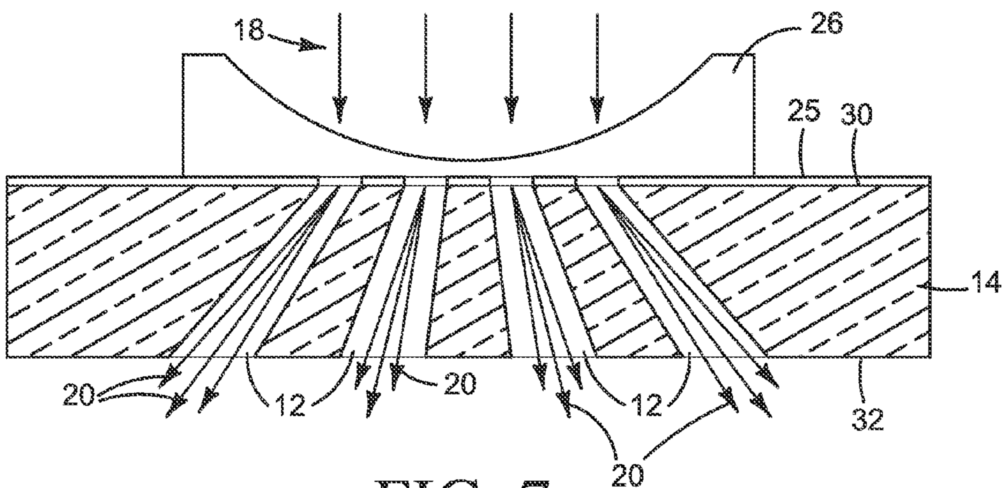

FIG. 7

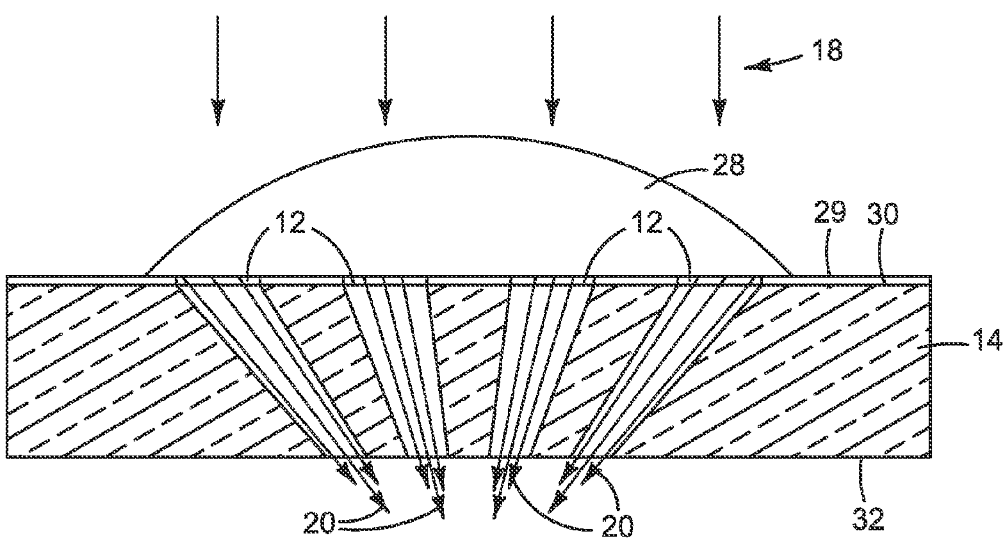

FIG. 8

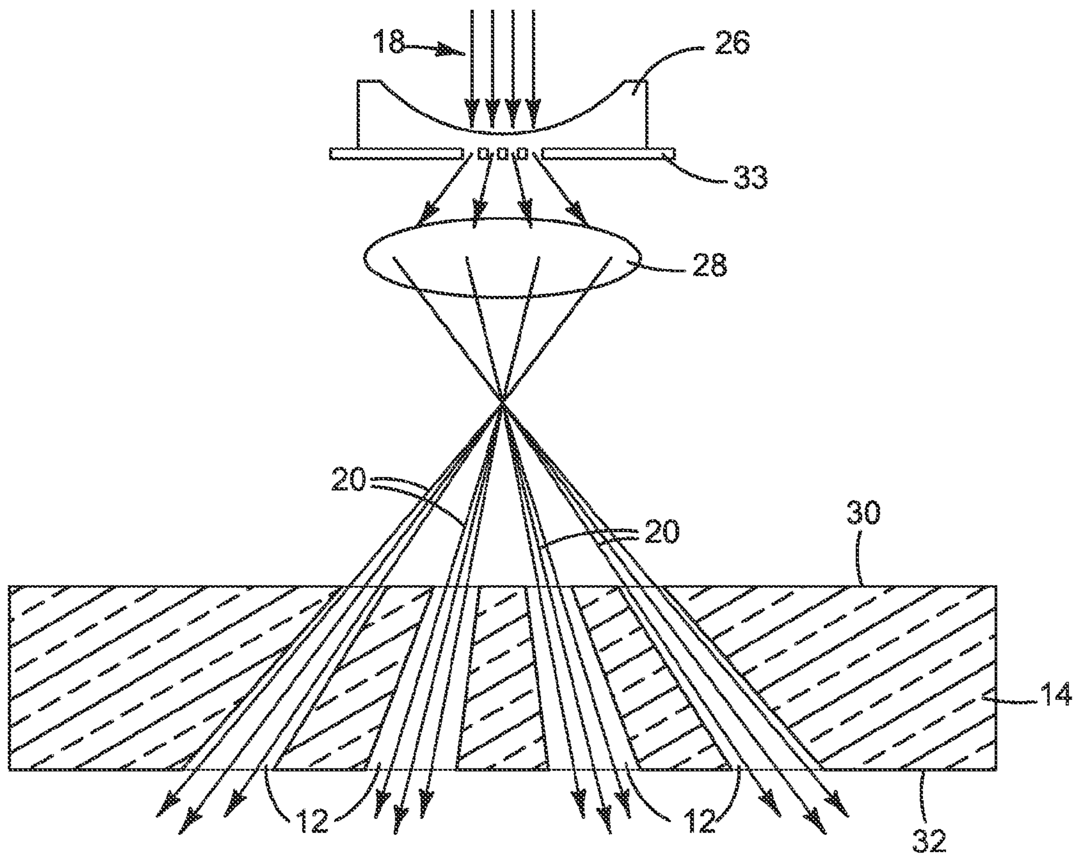

FIG. 9

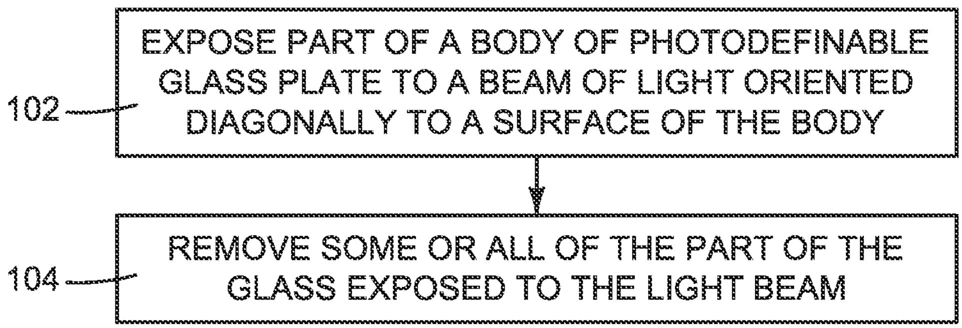
EXPOSE PART OF A BODY OF PHOTODEFINABLE GLASS PLATE TO A BEAM OF LIGHT ORIENTED DIAGONALLY TO A SURFACE OF THE BODY
102
REMOVE SOME OR ALL OF THE PART OF THE GLASS EXPOSED TO THE LIGHT BEAM
104

FIG. 10

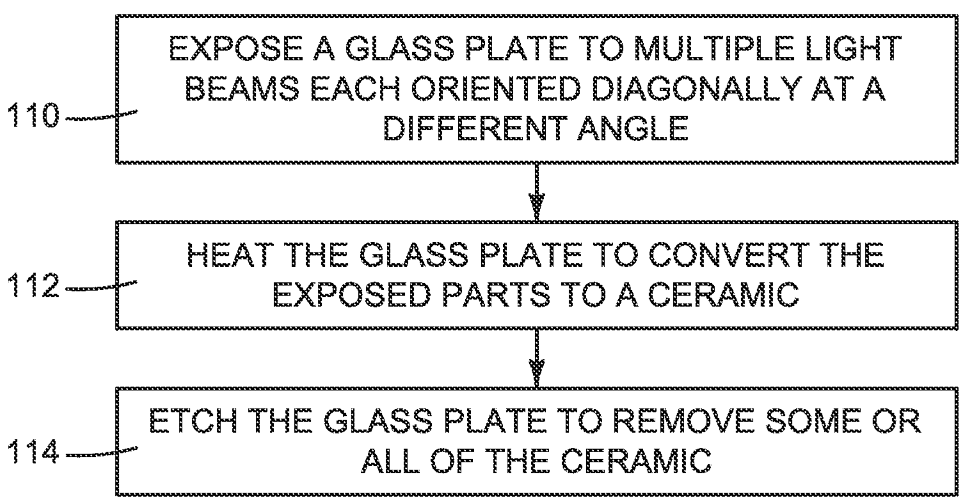
EXPOSE A GLASS PLATE TO MULTIPLE LIGHT BEAMS EACH ORIENTED DIAGONALLY AT A DIFFERENT ANGLE
110
HEAT THE GLASS PLATE TO CONVERT THE EXPOSED PARTS TO A CERAMIC
112
ETCH THE GLASS PLATE TO REMOVE SOME OR ALL OF THE CERAMIC
114

FIG. 11

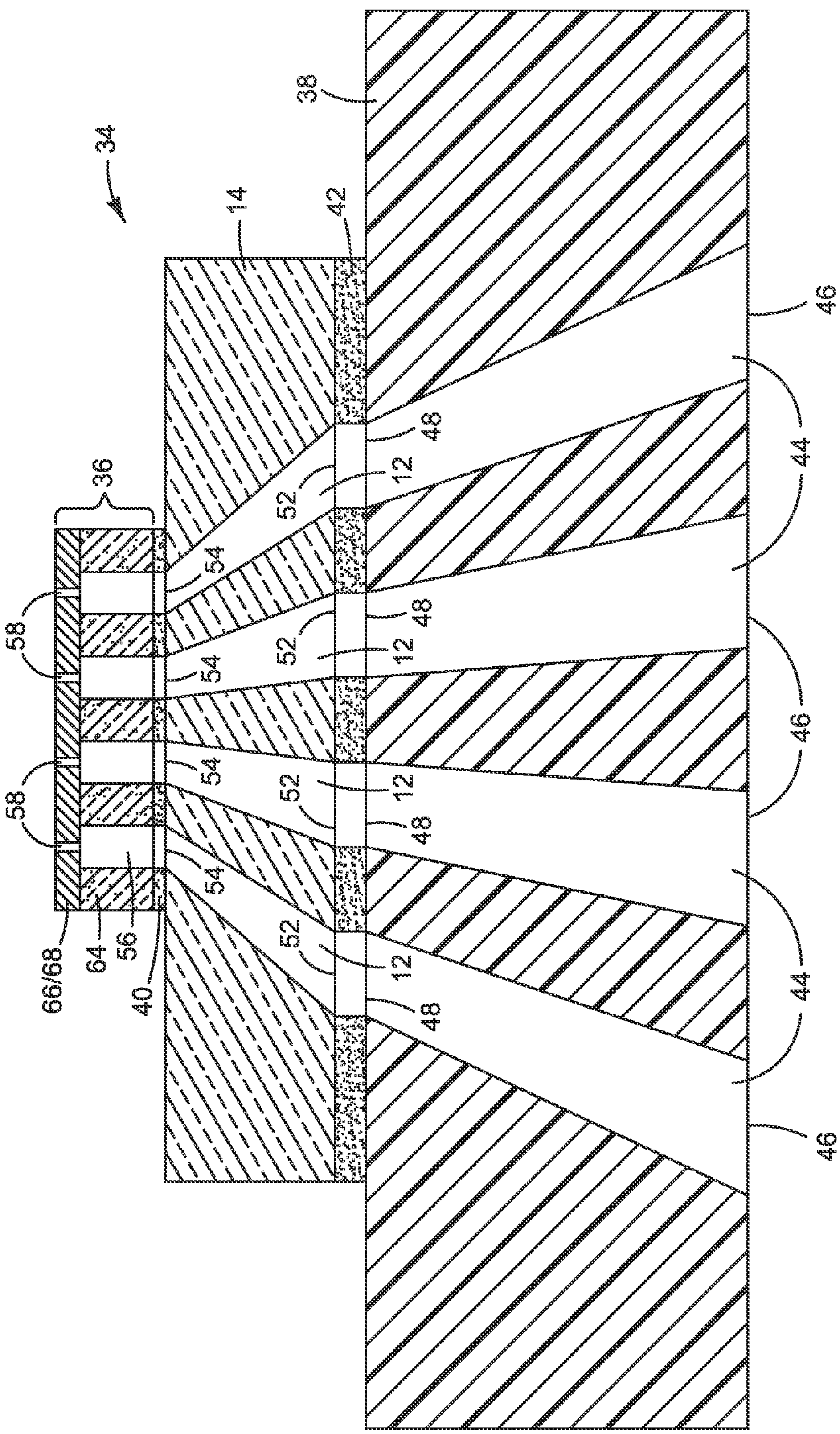

FIG. 12

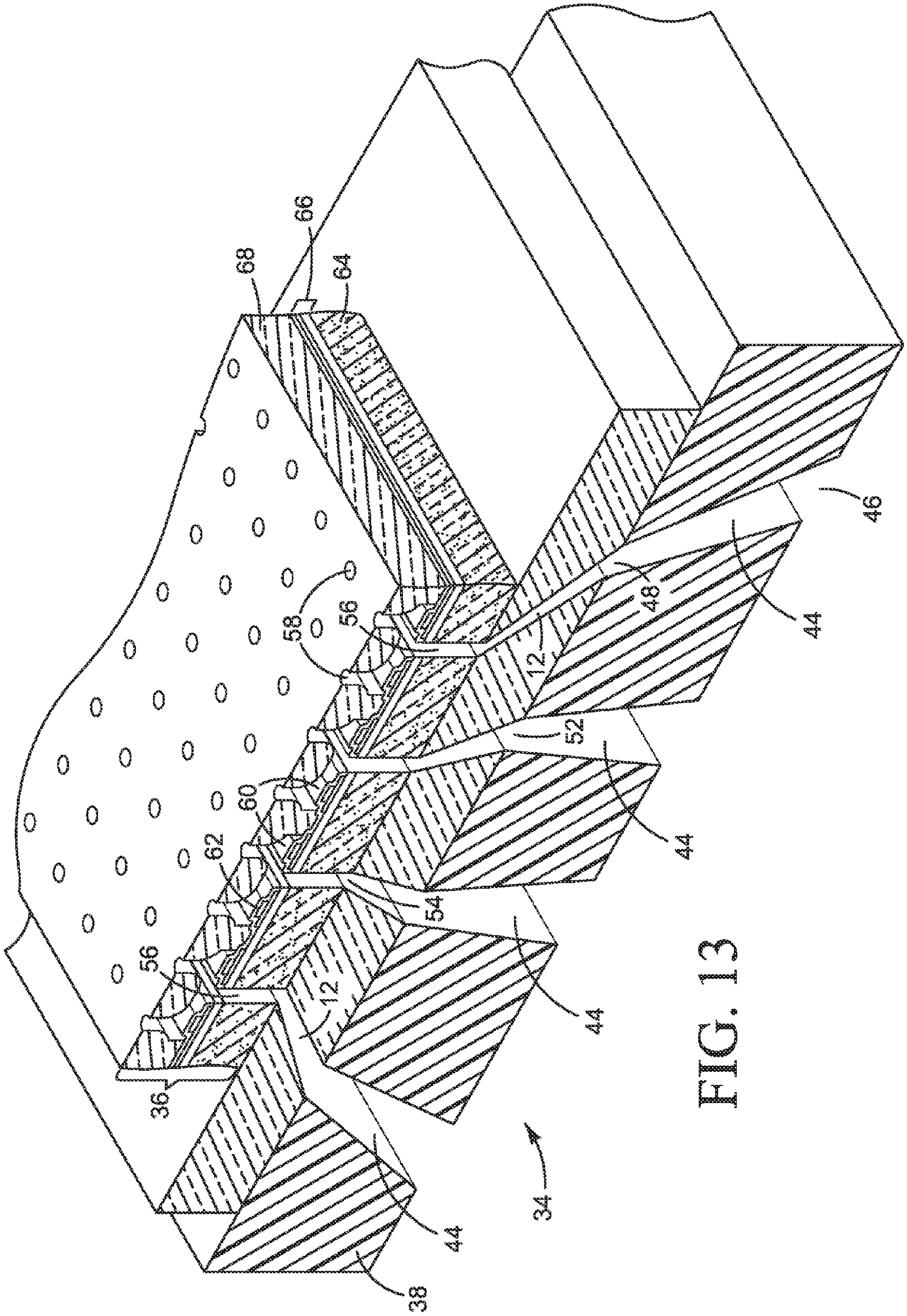

FIG. 13

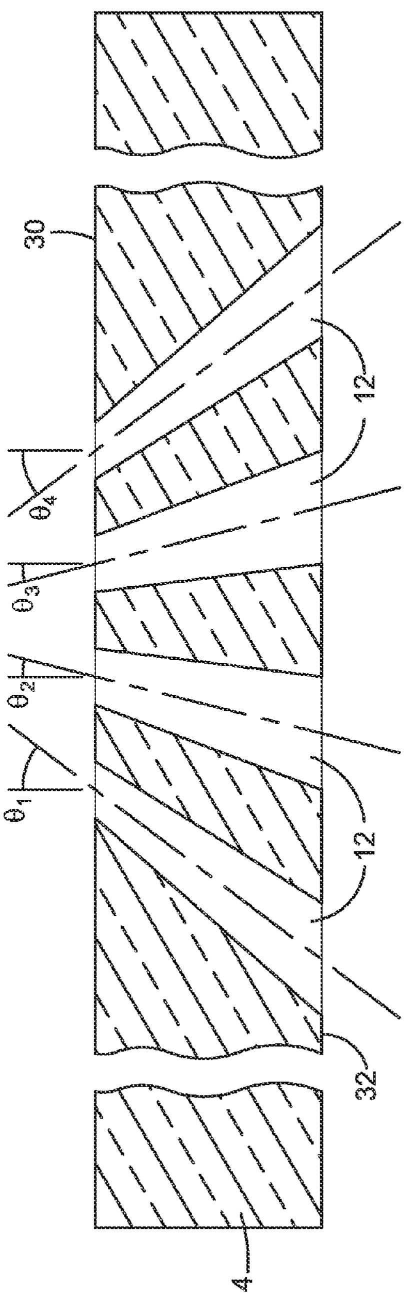
30
12
12
32
14
θ1
θ2
θ3
θ4

FIG. 14

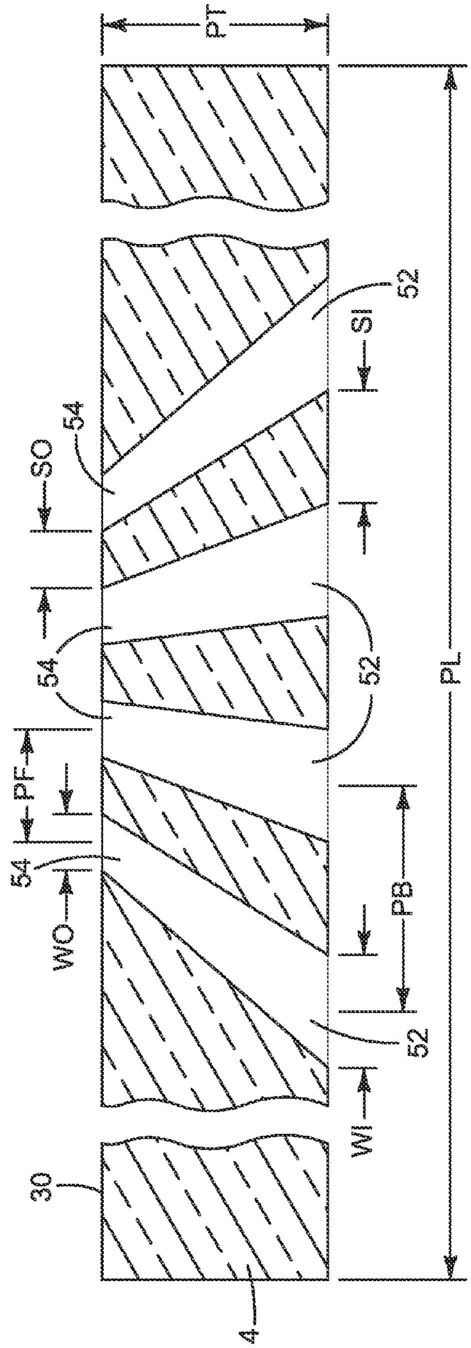
PT
PL
52
SI
54
SO
54
52
PF
PB
54
WO
52
WI
30
14

FIG. 15

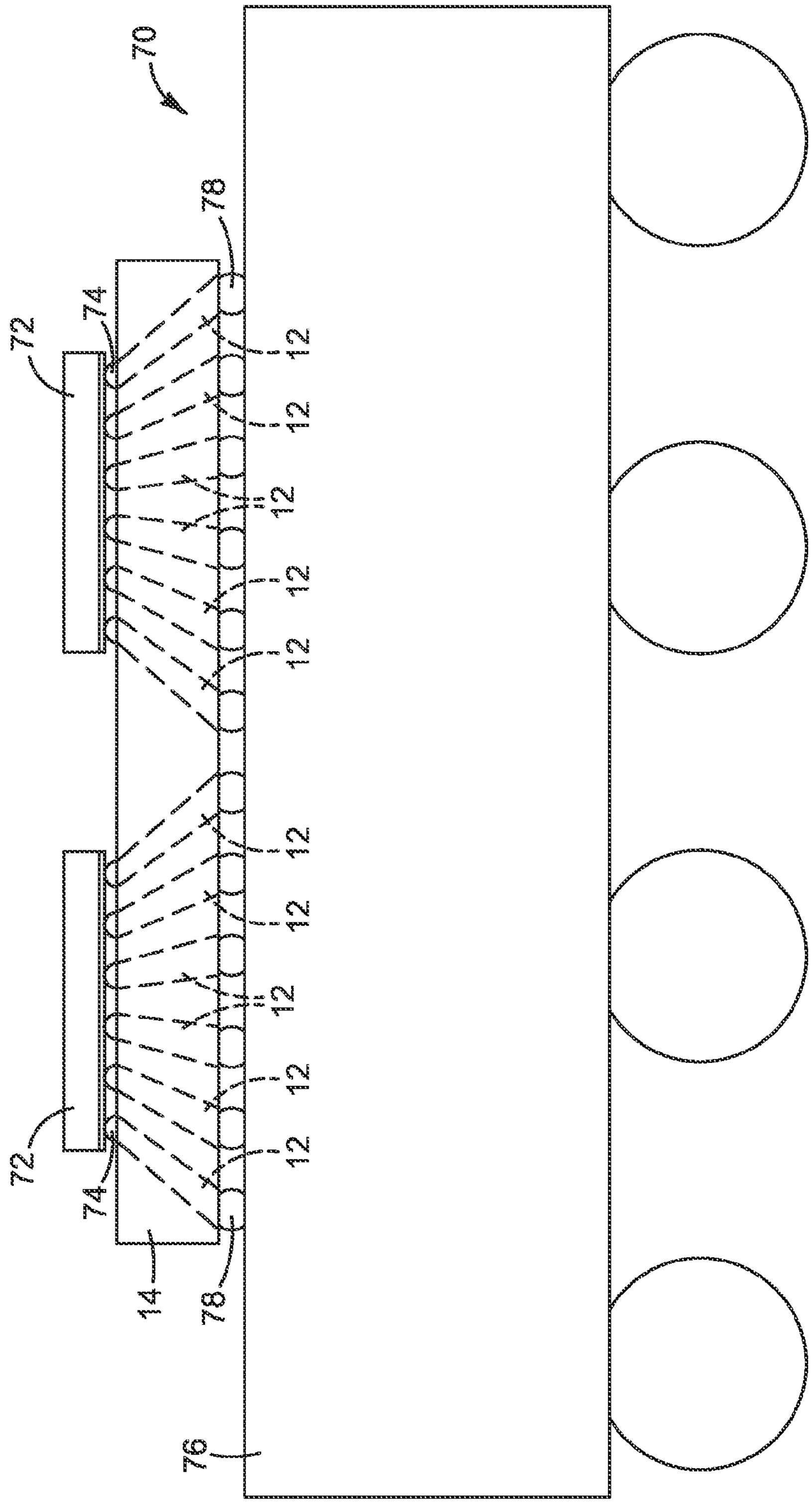

FIG. 16

DIAGONAL OPENINGS IN PHOTODEFINABLE GLASS

BACKGROUND

Each printhead die in an inkjet pen or print bar includes tiny slots that channel ink to the ejection chambers. Ink is distributed from the ink supply to the die slots through passages in a structure that supports the printhead die(s) on the pen or print bar. It may be desirable to shrink the size of each printhead die, for example to reduce the cost of the die and, accordingly, to reduce the cost of the pen or print bar.

DRAWINGS

FIGS. **1** and **2** illustrate one example of an array of diagonally oriented openings in a photodefinable glass plate in which circular openings in a uniform pattern are oriented at the same angle.

FIGS. **3** and **4** illustrate another example of an array of diagonally oriented openings in a photodefinable glass plate in which slots in a fanned out pattern are oriented at different angles.

FIGS. **5-9** illustrate example exposure systems that might be used to form diagonal slots.

FIGS. **10** and **11** are flow charts illustrating two examples methods for making diagonal openings in a photodefinable glass plate.

FIGS. **12** and **13** illustrate an inkjet printhead assembly implementing one example of the new diagonal openings in a photodefinable glass interposer.

FIGS. **14** and **15** are details views of the interposer in the printhead of FIG. **14**.

FIG. **16** illustrates an integrated circuit (IC) assembly implementing another example of the new diagonal openings in a photodefinable glass interposer.

The same part numbers designate the same or similar parts throughout the figures.

DESCRIPTION

Increasing the number of inkjet printhead dies that can be fabricated from a single wafer by shrinking the size of each die can significantly reduce the cost of the dies. The use of smaller dies, however, can require changes to the larger structures that support the dies on the pen or print bar, including the passages that distribute ink to the dies. For example, injection molded distribution manifolds are currently limited to a slot-to-slot spacing of about 800 μm while new printhead dies are being developed with a tighter slot spacing of 500 μm or less. Also, injection molded parts are not very flat, requiring thick adhesive layers for good bonding, which further limits die shrink.

It has been discovered that very small diagonal openings can be precisely formed in photodefinable glass so that small glass plates can be used effectively as interposers with fan-out ink slots to support printhead dies with a tighter slot spacing. U.S. Pat. No. 7,288,417 shows fan-out, expanding ink slots in a glass interposer that the inventors therein "believed" could be formed using glass machining techniques such as sand blasting, laser ablation, molding, and mechanical drilling. (Referring to column 8, lines 5-13 and FIG. 6 of the '417 Patent.) This belief, however, has proved to be misplaced, at least for the fabrication of glass interposers on the very small scale needed for use in inkjet printheads. Unlike conventional glass machining, laser ablation and etching techniques which thus far have been

inadequate for fabricating a suitable fan-out glass interposer, the current development of new exposure techniques for photodefinable glass suggests batch processing can be used to cost effectively produce glass fan-out interposers desirable for supporting further printhead die shrink. In addition to supporting tight slot spacing, photodefinable glass interposers can be made very flat, allowing the use of thin adhesive layers, and glass is a good CTE (coefficient of thermal expansion) match for the silicon printhead dies to minimize stress at the die bond interface.

In one example exposure method, a mask or lens (or both) is used to separate a collimated light beam into multiple smaller beams and direct those beams toward a photodefinable glass plate to expose the glass at the desired diagonal. The exposed part of the glass is then removed to form diagonal openings in the glass. In one specific implementation that might be used as an ink slot interposer for a printhead die, multiple slots extending diagonally through the glass plate are formed in a fan-out pattern in which the slot spacing is tighter at one surface of the plate (which would attach to the printhead die) and looser at the opposite surface of the plate (which would attach to the pen body or print bar).

Examples are not limited to implementation as interposers or in printhead dies, but might also include implementations as substrates or other components and in other types of devices. Accordingly, these and other examples shown in the figures and described below illustrate but do not limit the invention, which is defined in the Claims following this Description.

As used in this document, "photodefinable glass" means glass in which openings may be formed by exposing the glass to light and then removing parts of the glass exposed to the light without using machining techniques like sand blasting, laser ablation, molding, or mechanical drilling. Photodefinable glasses include, for example, Foturan™ glass manufactured by the Schott Glass Corp and Apex™ glass manufactured by Life Biosciences, Inc. Some photodefinable glass is also referred to as photosensitive glass or photostructurable glass or glass ceramic.

Also, as used in this document, "liquid" means a fluid not composed primarily of a gas or gases, and a "printhead" means that part of an inkjet printer or other inkjet type dispenser that dispenses liquid from one or more openings. A "printhead" is not limited to printing with ink but also includes inkjet type dispensing of other liquids and/or for uses other than printing.

Referring to FIGS. **1-4**, an array **10** of openings **12** are formed in a photodefinable glass plate **14**. In the examples shown, each opening **12** extends all the way through plate **10**, as a circular hole in the example of FIGS. **1-2** and as an expanding rectilinear slot in the example of FIGS. **3-4**. Although openings **12** through the glass plate are shown in the figures, diagonal openings **12** into but not through plate **10** may be desired for some applications. Also, although photodefinable glass structuring techniques could possibly be used to form larger scale structures, an important utility for such techniques lies in the formation of very small "micro" structures for which machining processes are ineffective or impractical. Thus, while no scale is indicated in FIGS. **1-4**, it is expected that diagonal openings **12** usually will be 50 μm to 1,000 μm in width formed in a glass plate **14** 0.5 mm to 2 mm thick.

In the past, straight openings have been formed perpendicular to the surface of a photodefinable glass plate for microfluidic structures for MEMS (micro electro mechanical systems) applications and as arrays of through glass vias

(TGVs) for integrated circuit packaging. Straight copper filled TGVs have been used to form electrical interconnects between the top and bottom of a photodefinable glass interposer, with redistribution layers added to the glass TGV to make an electrical fan out structure. It has been discovered that fan out structures can be formed in the photodefinable glass itself with new exposure techniques using structured lighting (projecting light with known spatial and angular constraints). Not only are diagonal openings possible with the new exposure techniques, but individual openings can be made to expand significantly through the glass and at different diagonals from other openings.

FIGS. **5-9** illustrate several example exposure systems that might be used to form diagonal fan out openings **12**. The tilt angle and width of individual light beams that illuminate the glass can be controlled, for example, by wavelength, mask opening size, shape, spacing and phase angle. In the exposure system of FIG. **5**, a phase shifting mask or diffraction grating **16** is used to illuminate glass plate **14** in the desired pattern for openings **12**. For a phase mask **16**, coherent wave fronts in a collimated light beam **18** from a laser or other suitable light source will encounter different indices of refraction at different locations due to steps formed in the mask. The wave fronts interfere to form the desired pattern of light beams **20** that illuminate glass plate **14**. For a diffraction grating **16**, the periodic structure splits and diffracts collimated source beam **18** into multiple beams **20** travelling in different directions. The directions of beams **20** depend on the spacing of the slits in the grating and the wavelength of the light.

In the exposure system of FIG. **6**, a two sided mask **21** imaged to the front and back surfaces of the mask is used with lenses **22**, **24** to focus non-collimated light into light beams **20** directed on to glass plate **14** in the desired pattern. The NA (numerical aperture) of the system must be large enough to cover the desired angles of beams **20** while still controlling cross-talk between the openings **12**. In the exposure systems of FIGS. **7** and **8**, a contact mask **25** is used with a negative cylindrical lens **26** (FIG. **7**) or a positive cylindrical lens **28** on or above a surface mask **29** (FIG. **8**) to direct beams **20** from a collimated light beam **18** on to glass plate **14** in the desired pattern. In the example shown in FIG. **7**, expanding light beams **20** diverge at different angles to pattern openings **12** that fan out and enlarge from front surface **30** to back surface **32**. In the example shown in FIG. **8**, contracting light beams **20** converge at different angles to pattern openings **12** that converge and contract from front surface **30** to back surface **32**. In the exposure system of FIG. **9**, an imaged mask **33** with negative and positive lenses **26**, **28** simultaneously images two focal planes to direct beams **20** from a collimated light beam **18** on to glass plate **14** in the desired pattern.

Referring to FIG. **10**, a method for making a diagonal opening **12** includes exposing part of a body of photodefinable glass (e.g., glass plate **14**) to a beam of light oriented diagonally to a surface of the body (step **102**) and then removing some or all of the part of the glass exposed to the light beam (step **104**). In a more specific example method shown in FIG. **11**, a glass plate **14** is exposed to multiple light beams **20** each oriented at a different angle in the range of 5° to 50° measured with respect to a normal to the front surface **30** of plate **14** (step **110**). The value for an angle or range of angles as used in this document means the angle or range includes the value(s) without regard to the direction in which the angle is measured from a reference. Thus, an angle in the range of 5° to 50° means +5° to +50° and −5° to −50° where, for example, "+" indicates the angle is measured clockwise from a normal to front surface **30** and "−" indicates the angle is measured counterclockwise from a normal to front surface **30**. As shown in FIGS. **5-9**, the front surface **30** of plate **14** refers to the surface facing the light beam **20** during illumination and the back surface **32** of plate **14** refers to the surface opposite front surface **30**. Glass plate **14** is then heated to change the composition of the exposed part of the glass to a ceramic or other material that can be etched preferentially with respect to the unexposed part of the glass (step **112**), and then glass plate **14** is etched to remove some or all of the ceramic part of the plate **14** (step **114**).

In one example, the following parameters may be applied to the method of FIG. **11** for a 0.5 mm-1.0 mm thick photodefinable glass plate such as Apex™ glass.

Exposing: 10.0-24.0 J/cm2 at 310 nm (mid-wavelength UV light).

Heating: bake at 500° C. for 75 minutes at 6° C. minimum ramp rate and then bake at 575° C. for 75 minutes at 3° C. minimum ramp rate.

Etching: 10:1 mix of water and 49% hydrofluoric acid in an ultrasonic bath.

FIGS. **12** and **13** illustrate a printhead assembly **34** implementing one example of the new diagonal openings **12** in a glass interposer **14**. FIGS. **12** and **13** depict similar structures in which printhead assembly **34** includes a printhead **36** bonded to a glass interposer **14** bonded to a molded plastic ink distribution manifold **38**. FIG. **12** depicts a portion of a printhead **36** more generally while FIG. **13** depicts a portion of a printhead **36** in more detail specifically as a thermal inkjet printhead. Referring first to FIG. **12**, printhead **36** is bonded to glass interposer **14** with a first adhesive **40** and interposer **14** is bonded to ink distribution manifold **38** with a second adhesive **42**. (Adhesives **40** and **42** are omitted from FIG. **13** to better illustrate other parts of printhead assembly **34**.) A photodefinable glass interposer **14** can be easily and inexpensively manufactured with surfaces much flatter than the comparatively large surface topography typical of a molded plastic part. Accordingly, lower aspect-ratio adhesive lines may be used at the printhead bond interface, as best seen by comparing the thinner first adhesive **40** at the silicon/glass interface between printhead **38** and interposer **14** to the thicker second adhesive **42** at the glass/plastic interface between interposer **14** and manifold **38**.

Referring now to both FIGS. **12** and **13**, ink is carried from manifold **38** to printhead **36** through an array of passages that grow smaller and more compact as the ink is channeled toward printhead **36**. In the example shown, a set of fanned out passages **44** in manifold **38** carry ink from wider, loosely spaced inlets **46** to narrower, more tightly spaced outlets **48** at interposer **14**. A set of fanned out ink slots **12** in glass interposer **14** carry ink from wider, less tightly spaced inlets **52** at manifold **38** to narrower, more tightly spaced outlets **54** at printhead **36**. Uniformly shaped ink channels **56** in a printhead **36** carry ink to the ejection chambers where it is dispensed through an array of orifices **58**. In the example shown in FIG. **13**, each printhead ink channel **56** supplies ink to a pair of ejection chambers **60** each associated with a firing resistor **62** and orifice **58**. Printhead ink channels **56** are formed in a substrate **64** underlying an integrated circuit (IC) structure **66** that includes firing resistors **62** and an orifice plate **68** formed on IC structure **66**.

The development of exposure techniques that enable the fabrication of small, tightly spaced diagonal (fan out) slots in a glass interposer contributes significantly to the opportunity for further printhead die shrink. FIGS. **14** and **15** are detail views of interposer **14** from FIG. **12** showing one example configuration to support a printhead assembly that includes a new, smaller printhead such as might be used in the next generation of inkjet printer pens. Referring to FIGS. **14** and **15**, the size WO and spacing SO of slot outlets **54** can now be reduced to 250 μm to deliver ink or other liquids to equally small and tightly spaced printhead channels **56** (FIG. **12**) using a photodefinable glass interposer **14** with fan out slots **12**. Testing indicates it is possible to form suitable diagonal slots **12** at tilt angles θ in the range of 5° to 50°. Accordingly, fan out ratios of 2:1 can be achieved across thin glass plates suitable for use as a print interposer **14**. For example, to achieve a 2:1 fan out ratio for a 1 mm thick photodefinable glass plate **14** (PT=1 mm, PL=10 mm) with a center-to-center slot pitch PF of 500 μm at front surface **30** (width of outlet WO=250 μm and spacing between outlets SO=250 μm and a slot pitch PB of 1,000 μm at back surface **32** (width of inlet WI=500 μm and spacing between inlets SI=500 μm), tilt angles θ_1=+50°, θ_2=+20°, θ_3=−20°, and θ_4=−50° are required, well within the range of tilt angles possible with photodefinable glass interposer **14**. Conventional glass mechanical machining methods, on the other hand, are not capable of producing these size and shape openings.

FIG. **16** illustrates an integrated circuit (IC) assembly **70** implementing another example of the new diagonal openings **12** in a glass interposer **14**. Referring to FIG. **16**, IC assembly **70** includes a thin IC device **72** attached to a photodefinable glass interposer **14** through an array of first electrode bumps **74**. Glass interposer **14** is attached to a plastic packaging substrate **76** through an array of second electrode bumps **78**. The first and second electrode bumps **74**, **78** are electrically connected through a corresponding array of conductor filled through vias **12** that fan out from a tighter spacing at IC device **72** and first electrode bumps **74** to a looser spacing at packaging substrate **76** and second electrode bumps **78**.

As noted at the beginning of this Description, the examples shown in the figures and described above illustrate but do not limit the invention. Other examples are possible. Therefore, the foregoing description should not be construed to limit the scope of the invention, which is defined in the following claims.

What is claimed is:

1. A method, comprising:

concurrently forming a plurality of spaced nonparallel bundles of nonparallel rays; exposing part of a body of photodefinable glass to the plurality of nonparallel bundles of nonparallel rays, each bundle oriented diagonally to a surface of the body at an angle of 5° or greater measured with respect to a plane normal to the surface of the body; and

removing some or all of the part of the body exposed to the plurality of nonparallel bundles of nonparallel rays to form a diagonal opening in the body.

2. The method of claim **1**, wherein the body comprises a photodefinable glass plate, wherein each bundle is oriented diagonally to a surface of the plate at an angle in the range of 5-50° measured with respect to a plane normal to the surface of the plate and wherein the removing comprises removing some or all of the part of the glass plate exposed to the light beam to form a diagonal opening in the glass plate.

3. The method of claim **2**, wherein

a full thickness of the glass plate is exposed to the plurality of nonparallel bundles of nonparallel rays, wherein each of the plurality of nonparallel bundles of nonparallel rays are expanding and wherein the removing comprises removing the part of the glass plate exposed to the plurality of nonparallel bundles of nonparallel rays to form openings through the glass plate, each of the openings expanding from a smaller dimension at one surface of the plate to a larger dimension at an opposite surface of the plate.

4. The method of claim **1**, where the removing comprises:

heating the glass body to change the composition of the part of the glass body exposed to the light beam; and then

etching the glass body to remove some or all of the changed part of the glass body.

5. The method of claim **1**, wherein the nonparallel bundles of nonparallel rays diverge through the body.

6. The method of claim **1**, wherein the nonparallel bundles of nonparallel rays converge through the body.

7. The method of claim **1** comprising directing light through an optical arrangement to concurrently form the plurality of spaced nonparallel bundles of nonparallel rays, the optical arrangement being selected from a group of optical arrangements consisting of: (1) a phase shifting mask; (2) a diffraction grating; (3) a two-sided mask and lenses; (4) a negative cylindrical lens and a mask; (5) a positive cylindrical lens and a mask; and (6) a mask, a negative lens and a positive lens.

8. A method, comprising: concurrently forming a plurality of spaced nonparallel bundles of nonparallel rays; exposing part of a body of photodefinable glass plate to the plurality of nonparallel bundles of nonparallel rays, each of the plurality of nonparallel bundles of nonparallel rays being oriented diagonally to a surface of the plate at a different angle within the range of 5-50° measured with respect to a plane normal to the surface of the plate, and

removing some or all of each part of the glass plate exposed to the plurality of nonparallel bundles of nonparallel rays to form multiple openings through the glass plate, each of the multiple openings being oriented diagonally to the surface of the plate at a different angle.

9. The method of claim **8**, wherein each of the plurality of nonparallel bundles of nonparallel rays is expanding and wherein the removing comprises removing some or all of each part of the glass plate exposed to the plurality of nonparallel bundles of nonparallel rays to form multiple openings through the glass plate, each of the multiple openings being oriented diagonally to the surface of the plate at a different angle and expanding from a smaller dimension at one surface of the plate to a larger dimension at an opposite surface of the plate.

10. The method of claim **8**, wherein each of the plurality of nonparallel bundles of nonparallel rays is contracting; and wherein the removing comprises removing some or all of each part of the glass plate exposed to the plurality of nonparallel bundles of nonparallel rays to form multiple openings through the glass plate, each of the multiple openings being oriented diagonally to the surface of the plate at a different angle and contracting from a larger dimension at one surface of the plate to a smaller dimension at an opposite surface of the plate.

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